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CONDENSATION OF PURE He^3 AND ITS VAPOR
PRESSURES BETWEEN 1.2° AND ITS
CRITICAL POINT

by

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Date Declassified: December 3, 1948

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Technical Information Branch, Oak Ridge, Tennessee
AEC, Oak Ridge, Tenn., 4-8-49--850-A1508

Printed in USA

~~Price 5 Cents~~

DTIC QUALITY INSPECTED 2

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APR 21 1949

CONDENSATION OF PURE He^3 AND ITS VAPOR
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By S. G. Sydoriak, E. R. Grilly, and E. F. Hammel

On October 13, 1948 the authors succeeded in condensing¹ pure He^3 , that was prepared by E. S. Robinson and R. M. Potter of the laboratory. The isotope was "grown" from pure tritium solutions by β decay of the tritium. The latter was initially separated from traces of He^4 by passage through a palladium valve. The He^3 was purified by absorption of H_2 and T_2 in uranium, followed by repeated successive passages over (1) hot CuO followed by a liquid air trap, and (2) hot Ca , thus removing all other impurities except the rare gases.

These results seem especially interesting since so much doubt has existed over the properties of He^3 . London and Rice² suggested that this isotope would not liquefy at all, at least not under any "normal" conditions. Their argument was based on the large zero-point energy calculated for He^3 , which they found to be sufficient to compensate entirely the potential energy of the Van der Waal's cohesive energy. Tisza³ also doubted that He^3 would liquefy unless "entirely unheard of properties" of viscosity were exhibited by the liquid. Fairbank, Reynolds, and Lane⁴ measured the vapor pressure difference between He^4 and solutions enriched to 0.16 per cent He^3 in the temperature range from 1.3 to 4.2°K . Using ideal solution concepts, they calculated vapor pressures of pure He^3 . An extrapolation of $\log P$ vs. $1/T$, led to a normal boiling point of 2.9°K .

In these experiments 20 cu cm STP of He^3 was used. The He^3 was permitted to condense into the bottom of a 1.2 mm ID stainless steel capillary immersed in a bath of liquid-well helium at depths of, usually, 5 or 10 mm. The immersion depth was held constant by gradually raising the dewar as the bath evaporated, the capillary being fixed with respect to its vacuum system. A double Wilson seal surrounding the capillary made this immersion adjustment possible, even when pumping on the bath. In order to minimize the effect of the dead volume of the capillary in the temperature region between bath and room temperature, the upper part of the capillary was surrounded by two shells of heavier tubing in thermal contact with the capillary at the top (room temperature) end and at a point 4 cm from the bottom. Being far better heat conductors than the capillary, these shells had the effect of raising the temperature of the capillary at all points on the capillary not immersed in the liquid, thus greatly reducing the dead space.

The room temperature end of the capillary was connected to a combined mercury manometer and simple Toepler pump in such a way that by raising the mercury levels in the manometer, He^3 could be transferred into the capillary and its pressure there measured.

Condensation was assumed to be taking place if the equilibrium pressure in the capillary was independent of the volume of helium remaining in the manometer.

Figure 1 shows the data for three different temperatures. Flats on the two lower curves indicate the vapor pressures of He^3 corresponding to 3.19 and 3.29°K. Averaging temperature and pressure readings for all points definitely on a flat gives 3.189°K at 76.45 cm Hg and 3.285°K at 84.24 cm Hg.

The upper curve corresponds to a temperature of 3.38°K, which is believed to be above the critical temperature, T_c , since at T_c a horizontal inflection would be observed. From these data and other runs at intermediate temperatures we have chosen $T_c = 3.33^\circ\text{K}$.

In a number of instances, at temperatures below 2°K, it was noted that no rise in pressure followed the flat region, even when all the available He^3 had been admitted. This indicated that at low temperature we could no longer fill the cold portion of the capillary with liquid.

The vapor pressure measurements are summarized in Table 1 and in Figure 2, which also shows vapor pressures for He^4 , determined at Leiden in 1937. It is interesting to note that at 1.2°K the vapor pressure of He^3 is 35 times as great as that of He^4 , suggesting the potential usefulness of He^3 for thermometry at low temperatures. At 1°K He^4 vapor pressures are at the limit of accurate measurement. Indications are that He^3 could be used down to 0.5°K or perhaps even lower. The pressure at 0.5°K is 0.12 mm Hg if our data is extrapolated on the assumption of constant latent heat below 1.4°K.

A curve through the experimental points shows the normal boiling point to be 3.187°K. Extrapolation to the critical temperature gives for the critical pressure $p_c = 875$ mm Hg. Putting these values of p_c and T_c in Van der Waal's equation we find the critical density to be $\rho_c = 0.036$ g/cu cm. By Dieterici's equation, we find $\rho_c = 0.046$. Since for He^4 the accepted value of ρ_c lies midway between the values calculated from these two equations, we have chosen $\rho_c = 0.041$ g/cu cm. This is close to our experimental estimate at 3.29°K.

Table 1. Vapor Pressures of He^3 from 1.2 to 3.3°K.

$T, ^\circ\text{K}$	$P, \text{mm Hg}$	$T, ^\circ\text{K}$	$P, \text{mm Hg}$
1.199	22.8	2.568	365.6
1.322	31.6	2.805	494.8
1.512	53.7	3.020	634.1
1.623	69.9	3.189	764.5
1.783	99.3	3.285	842.4
1.965	140.8	3.323	872.0
2.035	159.2	(3.33)	(875.0) critical point
2.140	194.8	(3.187)	(760.0) boiling point
2.315	255.2		

REFERENCES

1. Although the evidence is not conclusive, indications are that we have observed a transition to a liquid rather than a solid state. This is suggested by the similarity of Figure 1 to what one would expect for a gas-liquid transition and by the approximate agreement between observed densities and those calculated from the critical constants by use of Van der Waal's and Dieterici's equations of state.
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4. Fairbank, H. A., C. A. Reynolds, C. T. Lane, B. B. McInteer, L. T. Aldrich, and A. O. Nier, Phys. Rev., 74, 345 (1948).

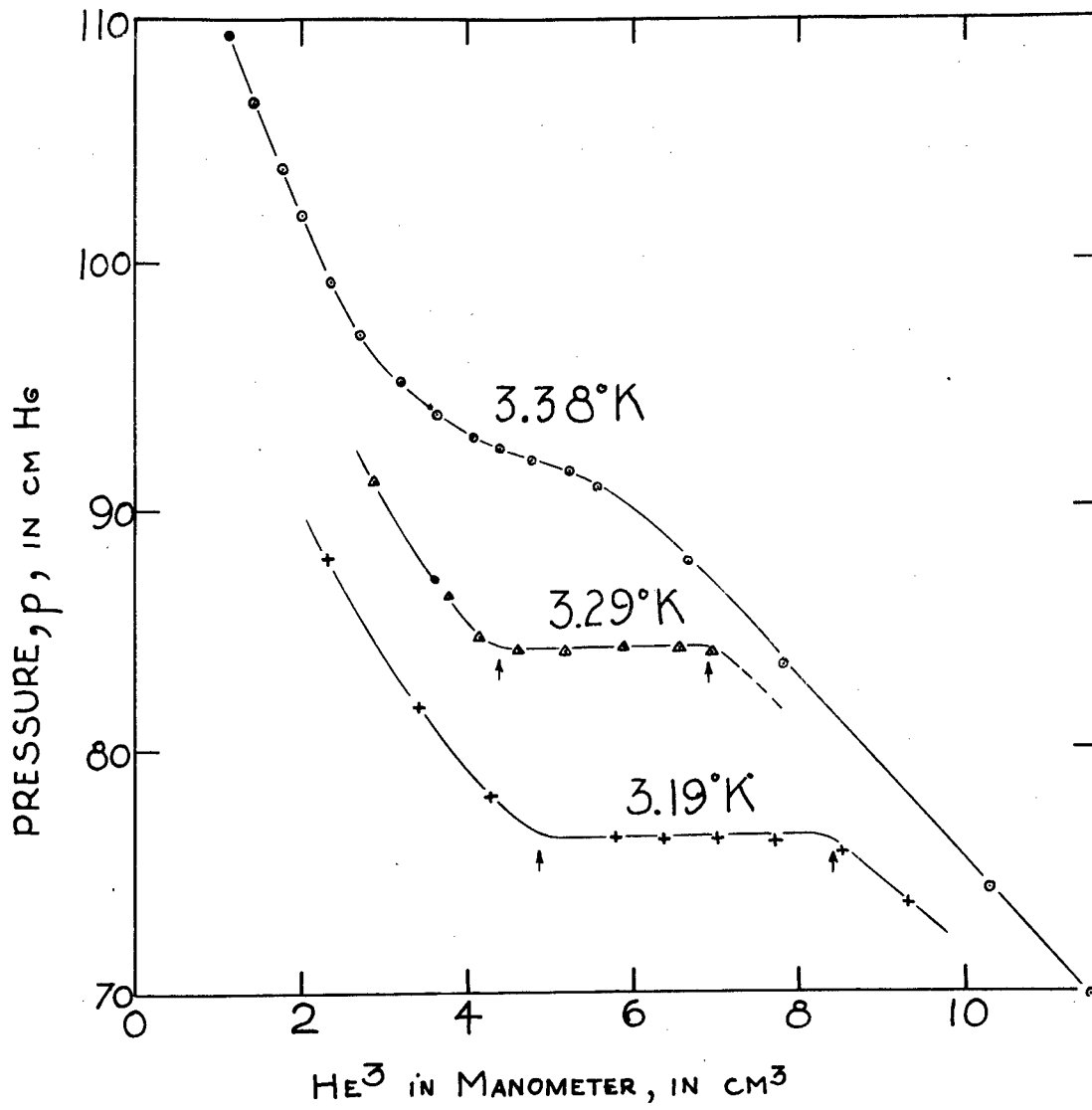


Figure 1. Vapor pressure of He^3 at three different temperatures.

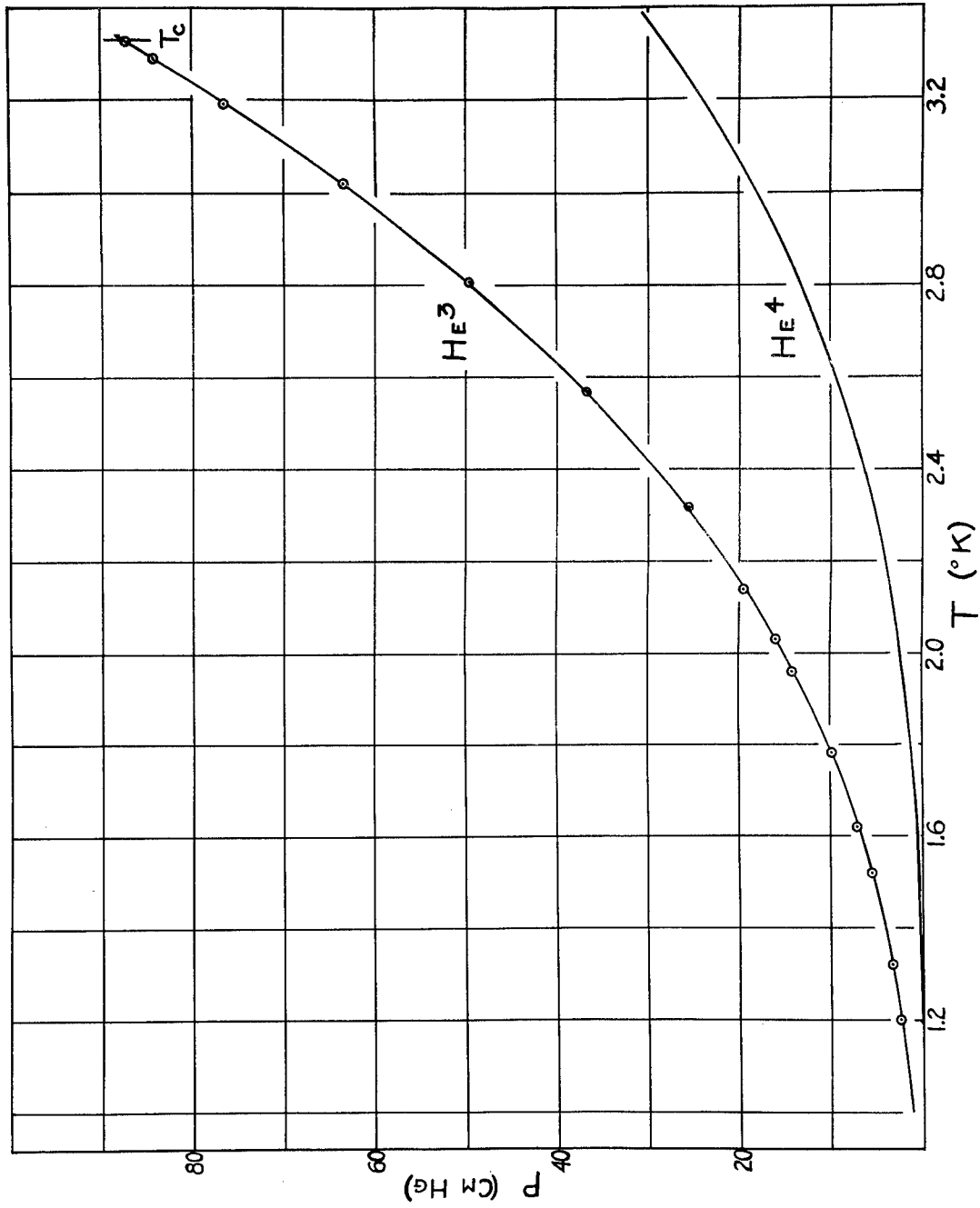


Figure 2. Summary of vapor pressure measurements.